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A socio-ecological approach to the declining Catalan clam fisheries

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A B S T R A C T

The world demand for marine bivalves continuously increased from 1980 to 2014. Their fisheries landings in the Mediterranean Sea also increased, until they began to drop in the last decade. This trend was particularly intense in the western Mediterranean Sea, where landings dropped from 4046 t (1996) to 425 t (2012). Since then, they have never recovered. We examined the status of the main commercial clam species in Catalonia (NW Mediterranean) one of the main productive areas of the western Mediterranean Sea, and analyzed the social and ecological context of the different small scale clam fisheries as an example of the Mediterranean as a whole to detect the possible causes of this negative trend. Our results reveal the critical status of all clam fisheries along the entire coast, where most clam stocks are currently collapsed or close to collapse. This trend mirrors the evolution of bivalve fisheries in the western Mediterranean. Many management failures and factors inhibiting the sustainability of clam fisheries over time were detected (*i.e.* the nearly absence of resource monitoring or control of rules enforcement; lack of conflict resolution mechanisms among fishermen and other coastal users; the incongruence between appropriation and provision regulations, and deficient nested enterprises), suggesting that inadequate and incongruent management is largely to blame for the precarious present situation. However, our results also suggest that undetermined additional factors (*e.g.* pathologies, pollution, climate change etc.) have also affected what were already highly stressed populations.

1. Introduction

Bivalve species are found at very high densities in many coastal marine systems. These large aggregations provide a wide range of keystone functions and services in the ecosystem (Norkko and Shumway, 2011) *i.e.* their presence, activity and abundance are crucial for the integrity, stability, organization and diversity of the entire ecosystem (Paine, 1969). Species inhabiting coastal areas (intertidal and subtidal) have been historically subjected to major fishing pressure, as they are easily accessible, relatively simple to harvest and a nutritious source of protein (Defeo, 2003; Gray, 2016).

The world demand for marine bivalves continuously increased last decades. Their production (fisheries and aquaculture) increased from 1980 (3.5 million tons), reaching 16.6 million of tons landed in 2014 (FAO, 2017). In the Mediterranean Sea their fisheries landings followed a similar trend, until they began to drop, with some fluctuations, during the last decade (Fig. 1A). This trend was particularly intense on the western Mediterranean Sea, where landings dropped from 4046 t (1996) to 425 t (2012) (Fig. 1B). Since then, they never recovered.

Clams are among the most valued and commercially exploited bivalve species in the Mediterranean Sea; the wedge clam (*Donax trunculus*), striped venus clam (*Chamelea gallina*) and smooth clam (*Callista chione*) being three of the most highly valued species. These clams are shallow-burrowing suspension-feeding organisms that inhabit clean sandy shallow grounds in coastal waters with a similar geographical distribution. Wedge clams inhabit highly energetic environments on sandy beaches (Brown and McLachlan, 2006) and are essentially distributed in well-sorted fine sand biocenosis between 0 and 3 m (Pérès and Picard, 1964). Striped venus clams inhabit a wider variety of sediment types (sand, sandy-mud and mud), being preferentially distributed on the well-sorted fine coastal sand biocenosis between 3 and 12 m in depth; whereas smooth clams occur in coarse sands between 5 and 20 m (Pérès and Picard, 1964; Baeta et al., 2014). However, these three species have very different growth rates, wedge clams reaching the minimum legal size before the first year of life (Ramón et al., 1995), striped venus clam before the second year (Ramón and Richardson, 1992), and smooth clam around 5 years in the Mediterranean coast of Spain (Baeta et al., 2014).

Most of the clam fisheries in the Mediterranean coast of Spain are small scale fisheries (SSF) (Baeta, 2006; Baeta et al., 2014). These type of fisheries have been poorly managed, monitored, and regulated in Europe despite their high social and ecological importance (Guyader, 2007). This is a direct consequence of the relatively low economic impact and volume of catches (Guyader et al., 2013). Small-scale clam

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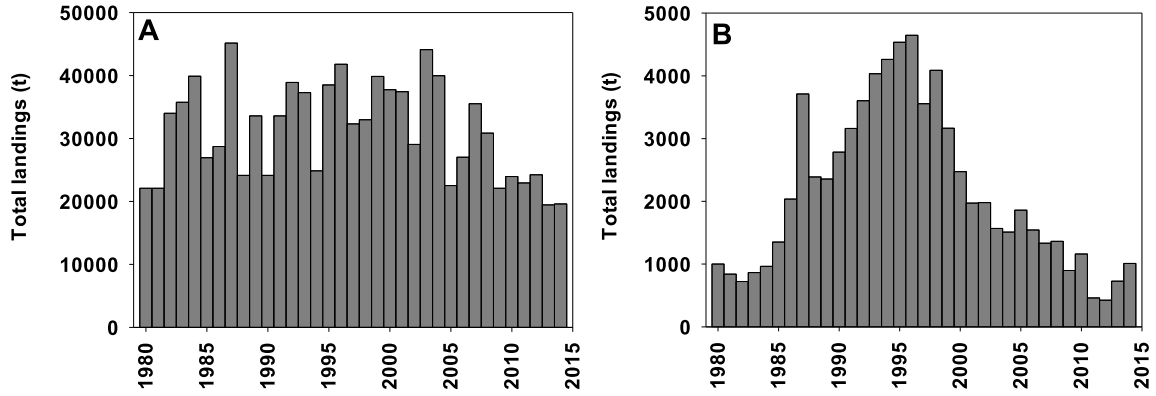

Fig. 1. (A) Total marine bivalve landings (excluding oysters and mussels) on the Mediterranean between 1980 and 2014; (B) Total marine bivalve landings (excluding oysters and mussels) on the western Mediterranean (Division 37.1.1 and 37.1.2) between 1980 and 2014 (FAO-GFCM, 2016).

fisheries have been described as a good example of "*common pool resources*" (CPR) (Steins and Edwards, 1999; Basurto, 2008; Beitl, 2011). CPR refers to systems where a natural resource is subtractable in order to generate a flow of goods and services for shared users, but at the same time is difficult to manage sustainably due to the difficulty of excluding undesired users (Dietz et al., 2002). In this system, the high level of uncertainty of future resource availability tempts users to maximize present benefits before others do likewise, thus reducing the incentives to invest in the sustainability of the resource and leading unequivocally to its inexorable degradation (tragedy of the commons) (Hardin, 1968; Basurto, 2005). Some of the well-known solutions proposed for this 'tragedy' have been applied to certain types of SSF (Cox et al., 2010), but not widely to clams. The most widespread is probably individual transferable quotas (ITQs) (*e.g.* Iceland, New Zealand and the USA), *i.e.* rights to harvest a certain volume of resource (Arnason, 2012). As an alternative to this approach, different levels of co-management have been implemented worldwide as useful tools for clam fishery management with encouraging results. Co-management consists of the sharing of government and local user responsibilities, rights, and duties (Pinkerton, 1989). Defeo et al. (2014) observed after the implementation of a co-management system for the yellow clam *Mesodesma mactroides* SSF at Barra del Chuy, Uruguay, significant improvement in the fishery. Landings were observed to stabilize at similar levels to early phases of exploitation, as well as the enhancement of bioeconomic indicators (i.e. Catch per Unit of Effort (CPUE), individual mean size, abundance, etc.). Similar results have been observed with the geoduck and horse-clam fishery in British Columbia, Canada (James, 2008). Notwithstanding, this approach might also fail, particularly in cases where there is a lack of community organization or governmental support (Castilla and Defeo, 2001). Ostrom (1990) defined the eight design principles that are suitable conditions to facilitate successful management of CPR. These principles are: (1) clearly defined user and resource boundaries; (2) congruence between appropriation and provision rules and local conditions; (3) collective-choice arrangements; (4) monitoring users and resources; (5) graduated sanctions; (6) conflict resolution mechanisms; (7) minimal recognition of rights to organize and (8) nested enterprises. Since then, these principles have been broadly tested, and most literature has proven them to be robust for SSFs worldwide (Cox et al., 2010). Despite the major importance of SSF for the Mediterranean Sea, most of the research done so far has typically focused on the ecological analysis of target species of the fishery, the management analysis being restricted to only one of these principles (*e.g.* "*congruence between appropriation and provision rules*" or "*the study of local conditions*"). Other studies have focused on a socio-economic approach to SSF (Tzanatos et al., 2006; Maynou et al., 2013), but none have evaluated the entire socio-ecological framework around an SSF. Moreover, there have been few empirical studies that have demonstrated the social and institutional conditions conducive to successful co-management outcomes (Cinner et al., 2012).

The objective of this paper is to analyze the social and ecological context of the different small scale clam fisheries on the Catalan coast of Spain (one of the main productive areas) as an example of the western Mediterranean in order to detect the possible causes of the drop in bivalve landings detected since 1996 in the region.

2. Socio-ecological framework

The study was carried out in Catalonia (Regional Autonomous Administration of northeast Spain) located in the northwestern Mediterranean (Fig. 2). The Catalan coast stretches for over 600 km from the French border (northeast) to the Ebro Delta (southwest). In Catalonia, The General Fisheries Directorate (GFD) of the "*Departament d'Agricultura, Ramaderia, Pesca i Alimentació*" (Catalan Government) is in charge of managing clam fisheries. It has legal authority over "territorial" waters (limited by straight lines connecting the tips of the capes) and jurisdiction over activities related to the capture of marine clams. There are four delimited clam fishing areas, which are located in shallow waters (< 30 m), and are geographically isolated. Clam fishing is forbidden outside of these areas, which are: (1) Rosas Bay: the smallest geographical area with a length of 15 km and with only one fishing port with clam fisheries, Rosas (Fig. 2); (2) North Barcelona: has 51 km of coastline, may be distinguished from the other areas by the coarse granulometry of the sand and the area includes three fishing ports with clam fisheries, namely Blanes, Arenys de Mar and Mataró; (3) South Barcelona has 70 km of coast, mainly fine sand beaches and includes three fishing ports in Barcelona, Sitges and Vilanova; and (4) the Ebro Delta: with an extension of 52 km of fine sandy beaches forming a delta, it has four ports with clam fishing activity (Alcanar, La Ràpita, Deltebre and l'Ampolla). Three of the fishing areas are currently open to commercial exploitation (Rosas Bay; South Barcelona and Delta Ebro), but one has been closed since December 2015 (North Barcelona) due to low landings.

Since the Catalan Government assumed the authority to manage clam fisheries from the Central Government of Spain in 1984, together with fishermen it developed certain clam species management plans (Table 1), which mainly described the appropriation rules and regulated standards for the fisheries of a clam species in a specific fishing area with only one fishing gear (*e.g.* clam dredges). They followed a bottom-up management system, developed by associations of clam fishermen and then the GFD created the legal framework. However, most clam fisheries in Catalonia showed a total absence of management. These management plans remained unaltered until 2014–2015, when two new plans replaced the previous ones: (1) a management plan for hand-operated dredges (a fishing gear), exclusively for the Ebro Delta area; and (2) another management plan for clam dredges (a fishing gear), including general rules for the four fishing areas and some

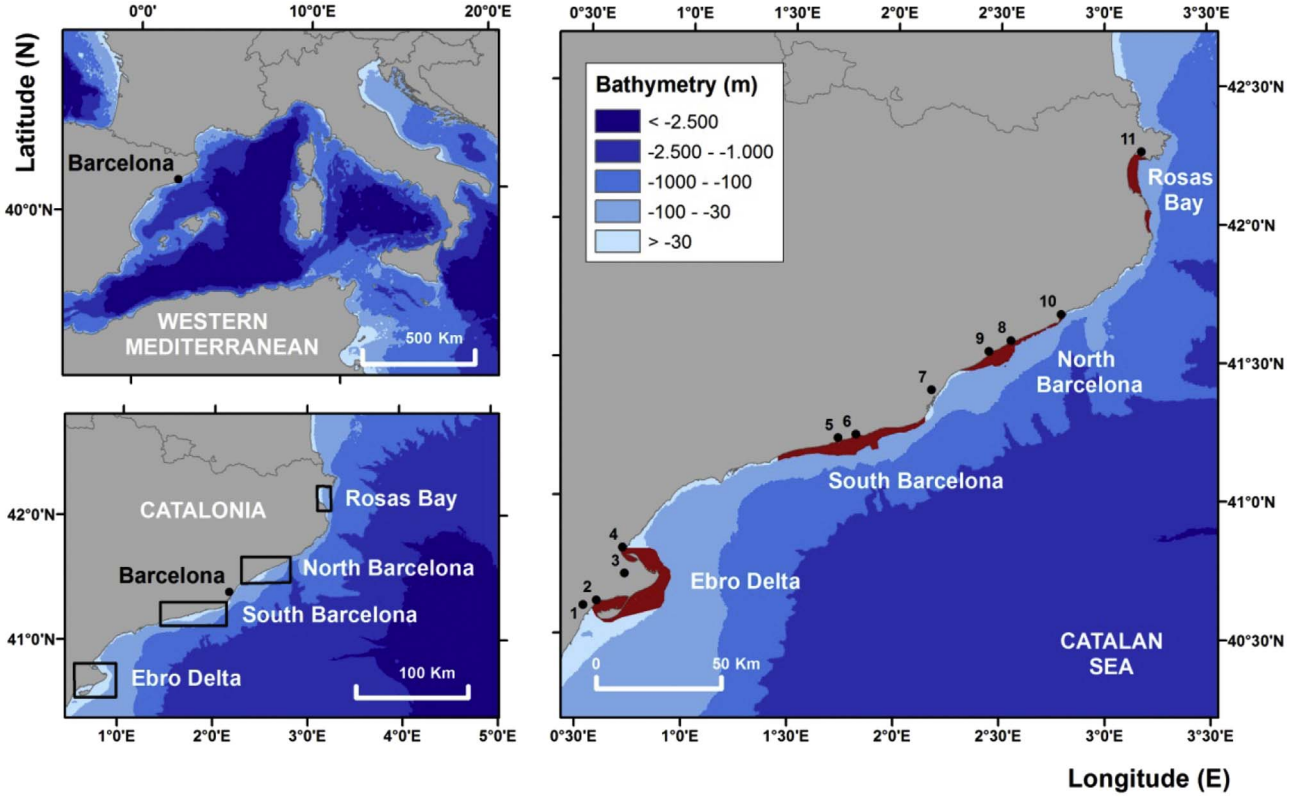

Fig. 2. Study area in the northwestern Mediterranean Sea, showing the 4 different clam fishing areas of the Catalan coast (Rosas Bay, North Barcelona, South Barcelona and Ebro Delta) and black spots indicate fishing ports with clam fisheries activity (1: Alcanar; 2: La Ràpita; 3: Deltebre; 4: Ampolla; 5: Vilanova; 6: Sitges; 7: Barcelona; 8: Mataró, 9: Arenys; 10: Blanes; and 11: Rosas).

specifications for each area. These second Management plans followed a top-down management system. Rules were defined by the GFD, whereas Fishermen's Guilds (including local clam fishermen associations) were merely informed about them. These new management plans are a compendium of rules and regulatory measures drawn up by the Catalan Government with null participation of the local fishing sector (fishermen's guilds and associations) designed to define the geographical limits of fishing areas, fishing gear (mesh size, dredge characteristics, boat specifications) and target species (minimum legal size, maximum catch limits etc.).

3. Methods

The analysis of the three different clam fisheries (wedge clam, striped venus clam and smooth clam) in the four delimited clam fishing areas existing on the Catalan coast (Rosas Bay; North Barcelona, South Barcelona and Ebro Delta) was made using official information on clam landings, legal documents from the Catalan Government, scientific literature and both informal and semi-structured interviews with fishermen.

3.1. Analysis of official landings

Official landing data for Catalonia were obtained from 2000 to 2015 (GFD database, unpublished). The data come from daily auctions by fishing gear, species and fishing area. Only data from clam dredges were evaluated because this is the principal clam fishing gear used in Catalonia. The Mann-Kendell non-parametric test was employed to detect temporal trends in total annual landings and CPUE by species and fishing area. Slopes were computed with Sen's robust estimator when statistically significant differences were detected ($p < .05$). A non-parametric Kruskal-Wallis test was used to determine differences in the resource appropriation of each species CPUE (wedge clam and striped venus) between fishing areas (Rosas Bay; South Barcelona and Ebro Delta). A Spearman's rank correlation coefficient was used to examine whether the oscillations in CPUE by species and fishing area are correlated ($p < .001$).

Table 1
Summary of the four clam fishing areas in Catalonia.

Fishing area	N ports	Target species	Fishing gear	Management plan	Year
Rosas Bay	1	wedge clam (*D. trunculus*)	clam dredges	Yes	1987
		striped venus clam (*C. gallina*)	clam dredges	No	
N. Barcelona	3	smooth clam (*C. chione*)	clam dredges	Yes	1988
S. Barcelona	3	wedge clam (*D. trunculus*)	clam dredges	No	
		striped venus clam (*C. gallina*)	clam dredges	No	
Ebro Delta	4	wedge clam (*D. trunculus*)	clam dredges	Yes	1994
			hand-operated dredges	No	
		striped venus clam (*C. gallina*)	clam dredges	No	
			beam trawl	No	

Table 2
Summary of the historic number of fishermen by area and fishing gear; the active fishermen at 2017 (none is dedicated exclusively to this activity) and the distribution of the semi-structured interviews.

Fishing area	Fishing gear	Fishermen	Active fishermen	Semi-structured interviews
Rosas Bay	clam dredge	46 (1980's)	2	4
N. Barcelona	clam dredge	32 (1980's)	0	4
S. Barcelona	clam dredge	200 (1960's)	4	4
	hand-operated dredge	50 (1960's)	0	0
Ebro Delta	clam dredge	40 (1960's)	4	4
	hand-operated dredge	200 (1960's)	77	4
	beam trawl	60 (1990's)	44	2

3.2. Management analysis

The analysis of clam fishery management was based on official information from legal documents from the Catalan Government, scientific literature and interviews. Initially, the Presidents of Fishermen's Guilds (N = 12) and senior fishermen (N = 10) along the whole Catalan coast were formally interviewed. They provided information about the history and management of clam fisheries, as well as contact information for clam fishermen. The snowball sampling technique was used to interview fishermen representing all the target clam species, all fishing areas and all fishing gears used on the Catalan coast to target clams. We conducted semi-structured interviews with these key fishermen (N = 22) between May and October 2016 (Table 2). In order to gain different perspectives on clam management, all the interviews were conducted following 10 different themes: (1) history of the fishery, (2) current situation and future perspectives; (3) user and resource characteristics; (4) rules and local conditions; (5) collective-choice arrangements; (6) monitoring users and resources; (7) sanctions; (8) conflict resolution mechanisms; (9) associations of clam fishermen and (10) nested enterprises. The interviews were recorded and the content was re-examined as appropriate to specific uses. The questionnaire used during the interviews is shown in Appendix 1.

4. Socio-ecological analysis of clam populations and management

4.1. Evolution of landings

Clam landings in Catalonia underwent major decline throughout the 2000–2015 period (Fig. 3). Wedge clam showed important fluctuations in landings from 2000 to 2006, between 75 and 225 t year^{-1}. After that, landings tended to descend to less than 15 t year^{-1} in 2015 (except 2013). Striped venus clam landings dropped from 2000 (292 t year^{-1}) to 2007 (7.54 t year^{-1}) (except 2005), thereafter showed important fluctuations but always < 40 t year^{-1}. Smooth clam landings declined progressively from 2001 to 2005, and then experienced a sudden fall in 2006 when their fisheries collapsed and never recovered afterwards. This negative tendency in landings occurred for all species in the 4 fishing areas (Table 3). However, this was particularly intense in the most productive areas, with an annual decrease of 12369 kg in smooth clam in North Barcelona and an annual decrease of 9608 kg in wedge clam and 1247 kg in striped venus clam in the Ebro Delta.

Resource appropriation (CPUE; mean kg boat^{-1} day^{-1}) showed significant differences ($p < .001$) for wedge clam and striped venus clam between the three fishing areas (Rosas Bay; South Barcelona and Ebro Delta), as a result of the different local environmental conditions. However we did not detect differences in the temporal trend by species and fishing area (Table 4).

4.2. Analysis of the institutions in charge of fisheries

Principle 1: Clearly defined user and resource boundaries

This principle contains two components: 1A User boundaries, understood as "*clear boundaries between legitimate users and nonusers must be clearly defined*"; and 1B Resource boundaries, *i.e.* "*clear boundaries are present that define a resource system and separate it from larger biophysical environment*" (Ostrom, 1990; Cox et al., 2010). Clams inhabiting soft bottoms are sedentary and benthic species. Their stocks are structured as "*metapopulations*", *i.e.* isolated subpopulations, but interconnected through pelagic larvae. Clam fisheries tend to exploit geographical areas that may be associated with subpopulations (Orensanz et al., 2006). Therefore, it is relatively easy for managers to define the geographical boundaries of the main clam stocks, because they only need to identify the spatial distribution of these subpopulations. In this regard, the GFD delimited four clam fishing areas: (1) Rosas Bay; (2) North Barcelona; (3) South Barcelona and (4) Ebro Delta (Fig. 2). Inside each geographic area, each clam species preferably inhabits different bathymetrical ranges, *i.e.* wedge clam between depths of 0 and 2 m, striped venus clam between 3 and 7 m and smooth clam between 10 and 25 m.

Legitimate users should be based on a Fishing Guild ("Confraria de Pescadors") and on a fishing port with fish auctions inside the geographical limits of one of the four clam fishing areas. Moreover, they might have a special fishing license for catching clams that allows fishermen to target clams with a defined fishing gear inside a specific clams fishing area. Licenses are issued exclusively by the GFD. According to the fishing gears used and the fishing area, there are three types of fishing licenses for legitimate users: (1) hand-operated dredges (small dredge towed on shallow coastal waters are exclusively used for wedge clam in the Ebro Delta area); (2) clam dredges (traditionally 4 dredges are towed along the seabed by a fishing boat) for wedge clam, striped venus clam and smooth clam in any fishing area; and (3) beam trawl (a type of bottom trawling using a boat) is exclusively used for striped venus clam in the Ebro Delta area. The Ebro Delta is the only area where two different fleets coexist, with different fishing gears and different fishing licenses that may target the same species. This implies that the same resources have two different legitimate users, without boundaries between them. Local clam fishers using the same fishing gear tend to group into clam fishermen associations, which are informal clusters that defend their mutual interests. However they have no legal power to manage these fisheries.

The number of clam fishing licenses was limited after the management plan for hand-operated dredging (Ebro Delta area, 2014) and the management plan for clam dredging (in the four areas, 2015) came into force. Beam trawling in the Ebro Delta area does not have a management plan yet. According to the interviews with fishermen, poaching does not exist or is not important, and only occurs exclusively and sporadically with regard to wedge clam in the Ebro Delta. In conclusion, resource boundaries are well defined, but the users boundaries are unclear (Table 5).

Principle 2: Congruence between regulations on appropriation and provision rules and local conditions.

This principle refers to the local conditions. "*Appropriation and provision rules are congruent with local social and environmental conditions*" (Ostrom, 1990; Cox et al., 2010). The GFD is almost the only authority that can officially limit appropriation and regulate provisions for the clam fisheries on the Catalan coast. Since the assumption of responsibilities in 1984, the regulations have been defined specifically for each of the four fishing areas, the minimum legal size of main target species being the only common feature for all the areas until the new management plans came into force (2014–2015). However, sometimes and additionally, associations of clam fishermen in the four fishing

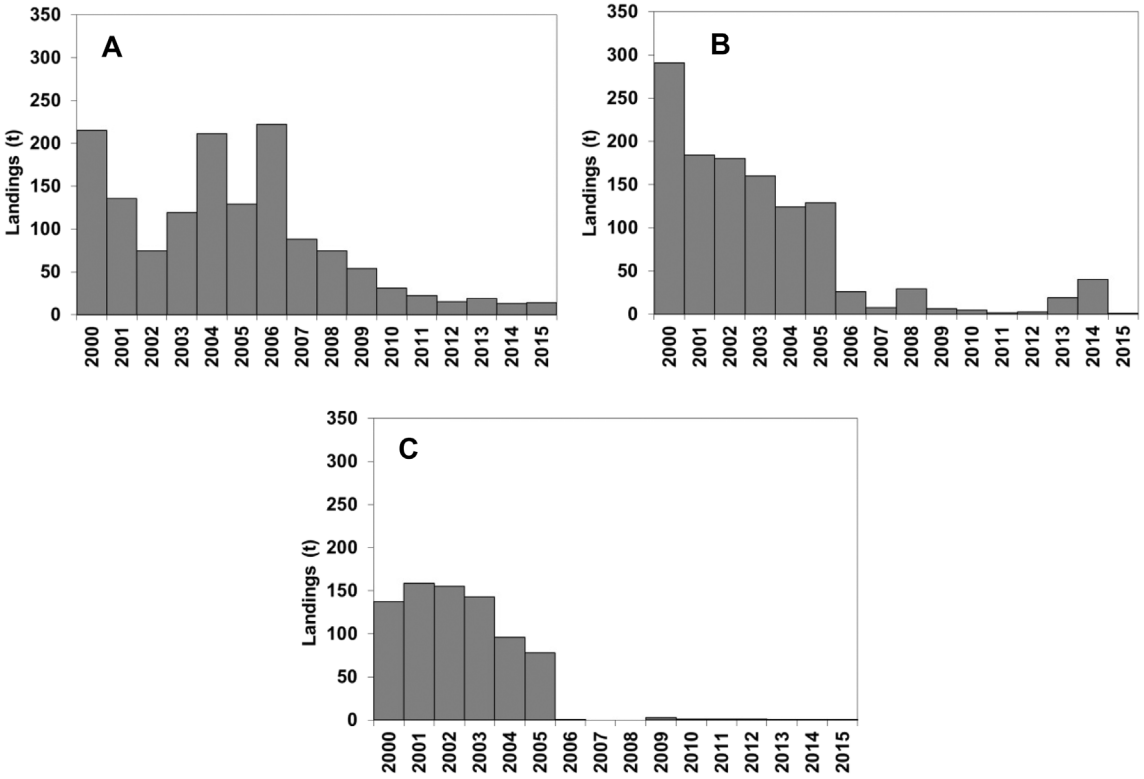

Fig. 3. Evolution of total annual landings (tons) of main commercial clam species on Catalonia. (A) wedge clam; (B) striped venus clam; and (C) smooth clam.

areas had their own internal regulations on appropriation.

Rosas Bay is the last geographic area where this fishery was developed in Catalonia (1980's). Striped venus clam landings began to decline very fast, and had become scarce by the early 1990's; and have never recovered since. Alternatively, wedge clam landings have dropped gradually since the 1980's and its fishery has been maintained until today. Today, there is a small fleet (3 boats) that combines clam fishing with other economic activities, which are often unrelated with fisheries and the sea. In the mid-1980's, the association of clam fishermen together with the Rosas Guild decided to regulate the activity by establishing some regulations on internal appropriation, such as a limitation on catches per day and boat, limitation of fishing time (two hours per day) and limitation of fishing days (an extra free day per week, *i.e.* Wednesday, was established). Later, in 1987, the GFD established, in accordance with the local fishermen's guild and local association of clam fishermen, an official management plan with some more restrictive regulations (*i.e.* appropriation limits per day and boat; machine to screen landings in Rosas Port and mesh size of 10×20 mm at the bottom of clam dredges). In these first years of clam fishery activity there was a mean daily catch of 200 kg per boat, which sporadically reached 500 kg per day and boat. However, the appropriation limit was fixed at 30 kg per day and boat (both for wedge clam and striped venus). The production surpluses were systematically sold outside official channels. Later, when landings began to decline, the

Table 4
Outputs from Spearman's correlation tests (Rs) used to compare the CPUE by species and fishing area ($p < .001$).

	S. Barcelona	Ebro Delta
wedge clam		
Rosas Bay	0.59	0.62
S. Barcelona		0.67
striped venus clam		
Rosas Bay	0.42	0.42
S. Barcelona		0.33

Table 3
The Mann-Kendell non-parametic test indicates temporal trends in Total annual landings (kg year^{-1}) and in CPUE (kg boat^{-1} year^{-1}) by species and fishing area on the period 2000 to 2015. Sen's slope indicates the annual oscillations.

Category	Total annual landings		CPUE	
	Mann-kendall Test	Sen's slope	Mann-kendall Test	Sen's slope
Rosas Bay				
wedge clam	$Z = -0.61$; $p < 0.001$	-877 kg year^{-1}	$Z = -0.62$; $p < 0.001$	-0.47 kg boat^{-1} year^{-1}
striped venus clam	$Z = -0.30$; $p < 0.05$	-13 kg year^{-1}	$Z = -0.50$; $p < 0.001$	-1.16 kg boat^{-1} year^{-1}
N. Barcelona				
smooth clam	$Z = -0.77$; $p < 0.001$	-12369 kg year^{-1}		
S. Barcelona				
wedge clam	$Z = -0.68$; $p < 0.001$	$-1{,}499$ kg year^{-1}	$Z = -0.57$; $p < 0.001$	-0.93 kg boat^{-1} year^{-1}
striped venus clam	$Z = -0.70$; $p < 0.001$	-273 kg year^{-1}	$Z = -0.86$; $p < 0.001$	-1.09 kg boat^{-1} year^{-1}
Ebro Delta				
wedge clam	$Z = -0.60$; $p < 0.001$	$-9{,}608$ kg year^{-1}		
striped venus clam	$Z = -0.33$; $p < 0.05$	$-1{,}247$ kg year^{-1}		

Table 5
Fulfillment of Ostrom's design principles in the four clam fishing areas of Catalonia.

Design principles (based on Ostrom, 1990 and Cox et al., 2010)	Rosas Bay	N. Barcelona	S. Barcelona	Ebro Delta
1. Clearly defined				
1A Resource boundaries	Yes	Yes	Yes	Yes
1B User boundaries	Partially	Partially	Partially	Partially
2. The congruence between appropriation and provision rules	No	No	No	No
3. Collective choice arrangements	Partially	Partially	Partially	Partially
4. Monitoring				
4A Rules enforcement	No	No	No	No
4B Resources	No	Partially	Partially	No
5. Graduated sanctions	Yes	Yes	Yes	Yes
6. Conflict resolution mechanisms				
6A Among fishermen	Yes	Partially	Partially	No
6B Among fishermen and other users	No	No	No	No
7. Minimal recognition of rights to organize	Yes	Yes	Yes	Yes
8. Nested enterprises	No	No	No	No

limit was never reviewed, despite drastically falling levels until 2015. A machine to screen capture was bought by the Rosas Guild in 1987 and all landings were screened to ensure sale only of individuals over the minimum legal size, and, theoretically, individuals below this limit were systematically returned to the sea. Unfortunately, fishermen segregated landings by size before bringing only those individuals over the minimum legal size to the machine and selling individuals under the minimum legal size limit unofficially. When landings began to decline in the 1990's, the machine was withdrawn and all individuals fished (including individuals under the minimum legal size) were sold at the Port. A minimum mesh size of 10 × 20 mm was established by the management plan. However, until recently, some fishermen have used a small mesh cover of 5 × 5 mm or 5 × 7 mm to target both species. In the late nineties, fishermen requested the authorities to define measures to stop the reduction in wedge clam landings. As a result, the GFD established two congruent measures to revert this negative trend in 2002, *i.e.* two closed seasons, the first (April–June) coinciding with the peak of gonadal maturation and spawning season, and a defined daily working schedule. Landings recovered in 2003. However, fishermen put again pressure on the GFD, but this time to invalidate the regulations established in the previous year. As a result, the Administration revoked the biological closures, but maintained the daily schedule. The management plan prevailed until 2015, when a new regulation was introduced for both species.

The main target species in the North Barcelona area is the smooth clam. The activity has been developed continuously from the 1960's, but the present technology (fishing gears, fishing winches and motor engines) was first used in the mid-1970's. Since then, the number of fishing boats increased progressively to 16 vessels in the 1980's, a level that was then maintained with few variations until the collapse in the mid-2000's. Catches of smooth clam began to drop in 1997 and, as a consequence, the local authorities commissioned a study of the status of smooth clam beds in 2004, resulting in the closure of the bed for commercial exploitation from March 2008 to April 2009 and an annual closed season in March and April for the following four years. The fishery was reopened in April 2009 but most of the fishermen had to abandon it due to the scarcity of the resource. Some occasional activity remained until the stock was closed officially in December 2015.

North Barcelona fishermen grouped to form a cooperative called CEMA that has managed smooth clam fishing since modern fishery began. They prompted the creation of a whole set of internal appropriation regulations for better management of the fishery. These measures were later made official through the smooth clam management plan of 1988, issued by the GFD. The management plan was the most ambitious and advanced plan of the entire coastline with a large number of ambitious regulatory measures such as a maximum number of fishing licenses, a maximum boat engine power, maximum landings per boat and day (150 kg), a minimum mesh size for clam dredges of 29 × 29 mm, daily time limitation, etc. Unfortunately, some of these appropriation regulations were never applied. Therefore, the management plan was a statement of intentions and guidelines rather than a legally enforceable agreement. In this regard, before the first closure of the fishery from March 2008 to April 2009, there was a clam fleet of 12 boats; most of which used clam dredges of 24 × 24 mm mesh size and some 12 × 12 mm, both types systematically targeted individuals under the minimum legal size (Fig. 4). Even though landings dropped from 1997, the appropriation regulations did not adapt to the new changing conditions, the same regulations being maintained until the collapse of the fishery.

Historically, the South Barcelona area had three clam landing ports; however, there is currently only certain activity in Vilanova and Sitges. It is not known when the striped venus clam and wedge clam fisheries began, but the use of the present technology (fishing gears, fishing winches and motor engines) was introduced in the seventies by fishermen coming from the Ebro Delta area. Hand-operated dredge activity disappeared in the early 2000's and the number of boats has continued to drop until the present day.

Despite the major importance of clam fisheries in South Barcelona, no official limitations on appropriation or provision regulations were established for striped venus clam and wedge clam landings until 2007, when as a result of requests to the authorities by some fishermen, the GFD established a minimum mesh size for clam dredges targeting wedge clam of 10 × 16 mm. According to fishermen's explanations, wedge clam fishery was like "*the wild west*", with no internal or appropriation regulations. The striped venus clam fishery was quite different from wedge clam. Fishermen had their own verbal appropriation regulations, which they called "*beach* agreements". Most of these regulations were based on the variations in stock status (*i.e.* the daily fishing effort and the maximum catch per day). However, most of the fishermen recognized on the interviews that "*once on boat they never screened the clams*". They systematically targeted individuals under the minimum legal size (Fig. 5). Interviewed fishermen justified the gathering of immature individuals under the minimum legal size because they are common in fish markets and shops proceeding from other areas (i.*e.* Spain, European Union and foreign countries). According to the management plan of 2015 fishermen can currently use clam dredges with a mesh size of 11 × 11 mm to target both species in the back part of the clam dredge. They are using 13 × 13 mm to target wedge clam and are not gathering striped venus clam.

The Ebro Delta area has historically been the most productive for wedge clam and striped venus clam landings, with four landing ports at les Cases d'Alcanar, Sant Carles de la Ràpita, Deltebre and l'Ampolla. It is also the only area where different fishing gears target the same species. Wedge clam is gathered by two different fishing gears (clam dredges and hand dredges) (Fig. 6A). Clam dredges operate between depths of 1 and 3 m, whereas hand-operated dredges operate from the

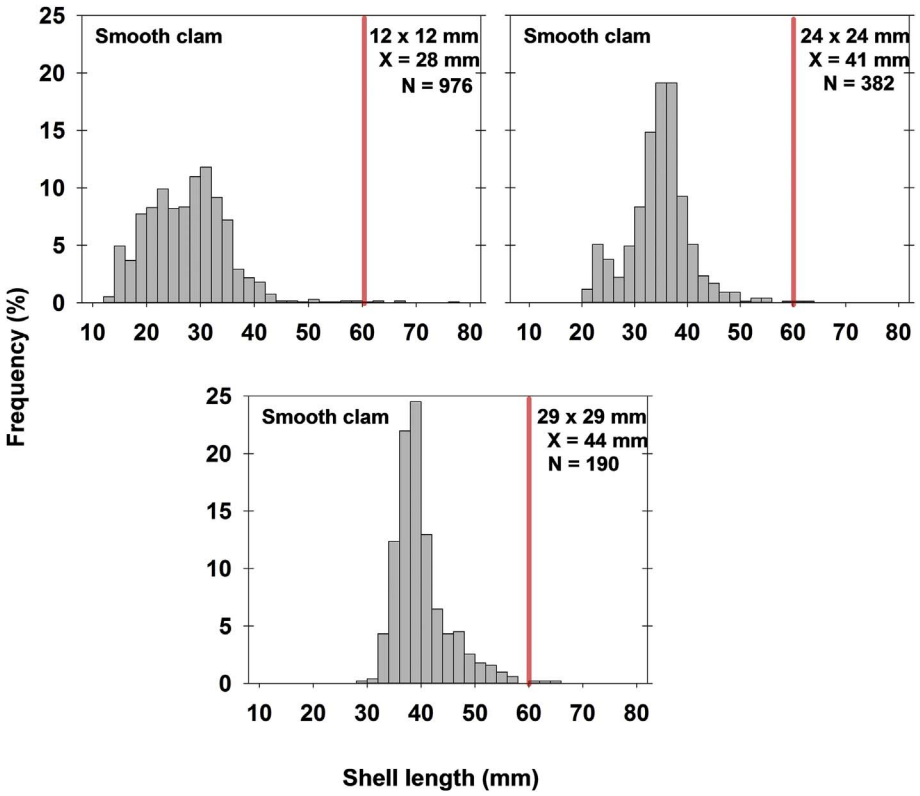

Fig. 4. Length-frequency distributions of smooth clam gathered using different clam dredges (mesh size of 12 × 12 mm; 24 × 24 mm and 29 × 29 mm) on North Barcelona clam fishing area. X indicates the mean size of the individuals; N indicates the total number of individuals sampled. Red line indicates the minimum legal size (60 mm) (Baeta and Ramón, 2007). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

mainland operate to depths of 1.5 m. The CPUE is higher using clam dredges rather than hand-operated dredges, but clam dredges target larger individuals, and hand-operated dredge smaller individuals. This clam has depth segregation; which means a predominance of smaller individuals between depths of 0.5 and 1 m and a prevalence of larger individuals (shell length ≤ 25 mm) at greater depths. The striped venus clam is equally gathered by two different fishing gears (clam dredges and local beam trawl) (Fig. 6B). The CPUE is higher using local beam trawl than clam dredges, but both work at the same depth. Fishermen using different fishing gears on the same species in the same place have different appropriation regulations, which is very confusing for them.

There has never been congruence between appropriation and

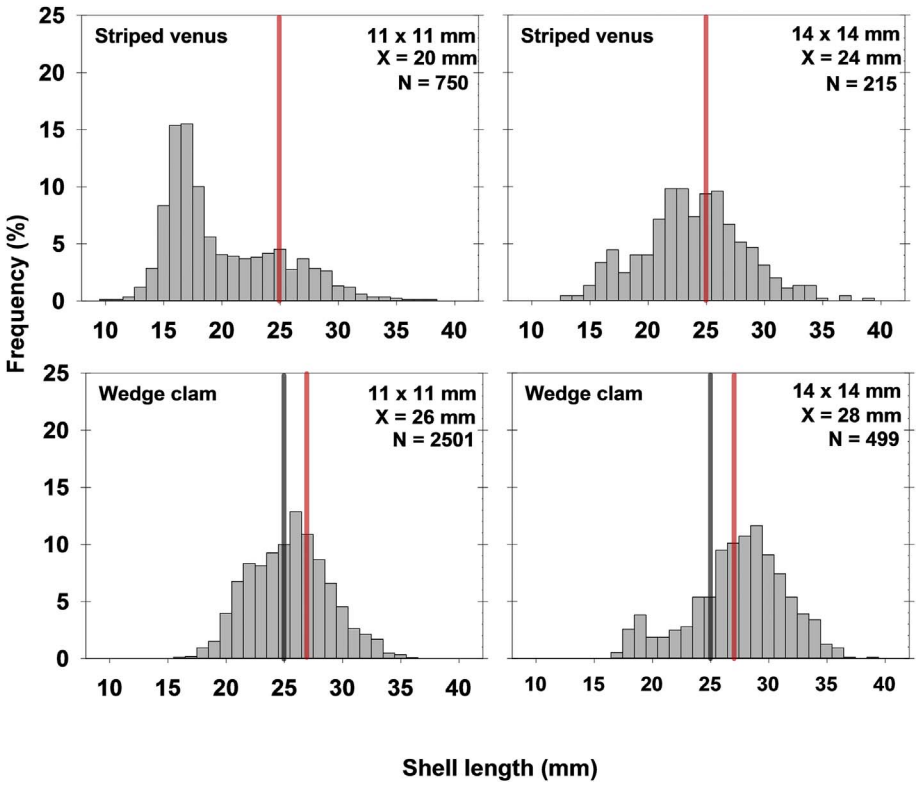

Fig. 5. Length-frequency distributions of striped venus clam and wedge clam using different clam dredges (mesh size: 11 × 11 mm and 14 × 14 mm) on south Barcelona clam fishing area. X indicates the mean size of the individuals; N indicates the total number of individuals sampled. Red line indicates the current minimum legal size for striped venus clam (25 mm) and for wedge clam (27.2 mm). Black line indicates the previous minimum legal size for wedge clam (25 mm) (Baeta, 2006). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

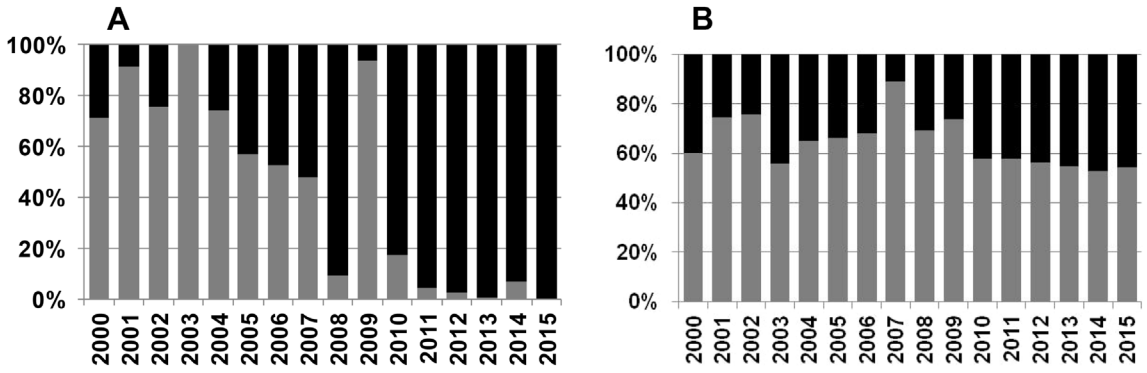

Fig. 6. Evolution of the annual proportion of the total landings per species (wedge clam and striped venus clam) captured by fishing gear on Delta Ebro area throughout the period 2000–2015. (A) Wedge clam landings, where grey indicates clam dredge and black hand-operated dredges landings; and (B) striped venus clam landings, where grey indicates clam dredge and black beam trawl landings.

provision regulations for any of the clam fisheries, nor for fishing areas (Table 5). In the few cases where some sort of provision regulations were established, such as the case of wedge clam in Rosas Bay and smooth clam in North Barcelona, these were totally overestimated, and never fixed under scientific advice. In all these cases, landing limits were fixed by fishermen, according to what they captured at the beginning of the fishery. When the clam dredge management plan came into force for all clam fishing areas in 2015, the provision regulations were implemented with new restrictive administrative measures; establishing for the first time common measures for the four fishing areas (i.e. fishing gear, fishing winches, motor engines and daily working schedule) and specific regulations for each area and target species (number of licenses, maximum number of fishing trips, and maximum landings per day and boat). In the case of the Ebro Delta, this was complemented by a specific management plan for hand dredging in 2014, which included a limitation on the number of licenses and daily working schedule.

Principle 3: Collective-choice arrangements

"*Legitimate users can participate in making and modifying their operational rules*" (Ostrom, 1990; Cox et al., 2010). Legitimate users (*i.e.* clam fishermen) had several mechanisms to participate in modifying operational regulations for the four clam fishing areas in Catalonia since the beginning of this fishery. All fishermen's guilds and associations of clam fishermen (within the fishermen's guilds) held regular meetings to discuss their own operational regulations, including most legitimate users (> 90%). Moreover, these organizations, as well as individual fishermen, had good relations with the GFD and could influence changes to these operational regulations. Good examples are the biological closures, daily work schedules and fishing areas where fishermen have felt the need for GFD support and this has been legally arranged. However, the lack of cohesion among clam fishermen (*e.g.* South Barcelona and Ebro Delta) and the high demand for clams from markets and restaurants have led to other internal and external regulations that are exclusively a declaration of intent, in particular related with the appropriation and provision regulations (Table 5). For example, legitimate users routinely failed to respect the minimum legal size of clam species, daily quotas or official sales pathways. This behavior has occurred regarding all clam species in all fishing areas. However, since the new management plans (2014 and 2015) came into force, all the collective choice arrangements have been completely ignored by the GFD, and since then all the regulations have followed a top-down system.

Principle 4: Monitoring users and resources

This principle contains two components: 4A Monitoring users, "*Monitoring to ensure rule enforcement*"; and 4B Monitoring resources "*Monitoring the environmental conditions of the resource*" (Ostrom, 1990; Cox et al., 2010). Neither the legitimate users (*i.e.* fishermen) nor the competent administration (GFD) have monitored the status of clam stocks since the transfer of competences in the 1980's. As an exception, some stocks have been evaluated on a one-off basis by the GFD as a result of the dramatic declines in catches. This body commissioned a study of the status of smooth clam beds in October 2004, resulting in the closure of the bed for commercial exploitation from March 2008 to April 2009 and an annual closed season in March and April for the following four years. The fishery was reopened in April 2009 and an extraordinary evaluation of the stock was again performed in May 2010, resulting in the closure of the bed for commercial exploitation in 2015. Another similar study of the status of wedge clam and striped venus clam on the South Barcelona coast was carried out in 2007, and as a result new regulatory measures were implemented for wedge clam (*e.g.* a minimum mesh size for wedge clam dredges).

The State Authorities conduct regular inspections of legitimate users and ensure compliance with appropriation regulations. However, the lack of resources, including lack of enforcement personnel, makes the control of users a titanic duty. Only some clam fishing ports have a fish market, so it is relatively easy to avoid the legal channels. This is particularly the case with hand-operated clam dredges, because fishermen do not have a set landing point, and they should go to port to sell their catch. According to interviews, clam dredges sell between 1 and 20% of daily landings illegally. The State Authorities have a database containing a list of the legitimate users of each fishing area and of each fishing gear.

Principle 5: Graduated sanctions

This principle states that "*users who violate the operational rules are subject to graduated sanctions (depending on the seriousness and context of the offense) by other users, by officials responsible for users, or by both.*" (Ostrom, 1990; Cox et al., 2010). Law 2/2010 establishes graduated sanctions for different types of offense; distinguishing three different levels: (1) minor infringements (between 60 and 300 Euros) (*e.g.* having an expired fishing license; fishing without the documentation on the boat); (2) serious infringements (between 301 and 6000 Euros) (*e.g.* fishing without mandatory licenses or permits; fishing outside the authorized territory; fishing individuals under the minimum legal size); and (3) very serious infringements (between 6001 and 60,000 Euros) (*e.g.* fishing in protected areas). The offences are well defined and penalties are proportionate. However, the operational regulations were unambitious until 2015 and inspections of the different clam fleets were rare. Although most of the operational regulations are respected, some of them are systematically breached (*e.g.* appropriation and provision regulations, such as points of sale, mesh size of clam dredges, minimum

legal size, etc.) in the four fishing areas; this implies that authorities are not enforcing with fishermen on the most restrictive appropriation regulations, to avoid a conflict with the sector. The interviews showed that fishermen rarely denounce each other, even when they know that some members of the collective are breaching the law; because none of them are 100% legal, and all of them break the law to a greater or lesser degree.

Principle 6: Conflict resolution mechanisms

"*Users and their officials have rapid access to low cost arenas to resolve local conflicts*" (Ostrom, 1990; Cox et al., 2010). There are different types of conflicts that affect clam fishermen. The first are internal, among different clam fishermen targeting the same species and in the same geographical area and with other fishermen using different fishing gears (targeting clams or not). Fishermen have historically had formal arenas for resolving these types of conflicts, whereby internal meetings are held to resolve any local problems; usually at the fishermen's guild in the port and include almost all the legitimate users of the fishery involved (clam fishermen). According to fishermen, these meetings are effective because everyone participates in them and they typically function as democratic assemblies, whereby what the majority decides is respected by everybody. In addition, each fishing guild located in a port has two legal figures that are responsible for mediating conflicts between fishermen, the President and the Secretary, who are periodically elected. However, the associations of clam fishermen have no elected leaderships, and are usually led by the most active and committed people, but sometimes also people who like power and influence. This mechanism has long existed and is respected by most fishermen. If internal conflicts cannot be resolved, the GFD plays the role of mediator and negotiator between parties. Most of the interviewed fishermen stated that, in general, there has historically been very little conflict among associated clam fisheries. Probably the only exception is the case of the Ebro Delta, where two different fishing gears target the same species in the same place, but have different appropriation and provision regulations. There, we detected an unresolved conflict among the users of the fishery, because each user group (users of different fishing gears) accuses the other of being partly to blame for the current situation. Moreover, users of the same fishing gear are not associated as a single group; they are associated as four different groups corresponding to the four fishing ports of the Ebro Delta fishing area. Each of these groups has its own internal appropriation regulations, which are different from those of the other three ports. This situation generates open warfare against everyone else (Table 5). However, there is an absence of local councils (in each clam fishing area) involving participation of all the different types of users of clam fisheries and the administration to define a single common management policy.

The second type of conflict is with other economic activities that coexist inside or contiguous to geographic areas delimitated for clam fisheries. There is no existing mechanism regarding such conflicts, which according to fishermen are mainly with sand mining and wastewater treatment plants. Particularly in the North and South Barcelona clam fishing areas, but occasionally in the other areas, some zones are considered sand deposits and have been used systematically to extract large amounts of sand for beach nourishment in the Metropolitan area of Barcelona.

Principle 7: Minimal recognition of rights to organize

"*The rights of users to devise their own institutions are recognized as legitimate by external governmental authorities*" (Ostrom, 1990; Cox et al., 2010). Fishermen have historically recognized the right to self-organize (Table 5). They are traditionally organized as Fishermen's Guilds by Port, whose administrators are cyclically elected and typically include members of the different fishing gears. Guilds are official institutions and act as mediators between fishermen and the Administration (Catalan Government, Spanish Government and European Commission). They are official collaborators with the Administration and receive its guidance and can cover all services that require fishermen to develop their activity. Sometimes inside these Guilds fishermen using the same fishing gear are grouped into associations (*e.g.* association of clam fishermen). These unions may be legal clusters (*e.g.* North Barcelona) working as cooperatives and acting as corporate lobbies inside the Fishermen Guilds and Administrations. However, they are generally informal groups that meet to discuss important matters (Rosas Bay; South Barcelona and Ebro Delta) affecting clam fisheries.

Principle 8: Nested enterprises

"*Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises*" (Ostrom, 1990; Cox et al., 2010). Coordination between the different administrative levels has hampered the management of clam fisheries in Catalonia (Table 5). The governance within the fishery sector is organized into multiple layers of nested enterprise (*i*.e. Fishermen, Fishermen's Guilds and Catalan Government). Actors involved in the fishery were weakly linked vertically and not horizontally (different fishing gears, different target species; different ports with different appropriation regulations inside the same clam fishing area). Vertically, the Catalan Government (GFD) is the only authority with responsibility for clam management in Catalonia. It might define regulations and monitor its compliance to ensure the sustainable exploitation of the natural resources in Catalonia. Unfortunately, the GFD defined a compendium of appropriation regulations without scientific advice, just to please the fishermen, leading the entire clam fisheries to be unsustainably exploited. The Administration focused its attention on clam fisheries when complaints from fishermen drew its attention to the startling decline in landings. At the same time, fishermen (including associations of clam fishermen and Fishermen's Guilds) are also responsible because they systematically broke some of the few appropriation regulations they had. Horizontally, the GFD did not create local councils (in each clam fishing area) that involved participation of all the different types of users involved to the present day in clam fisheries. This strongly affected the populations of commercially exploited clams, because different users had different appropriation regulations in the same areas. There is a major inconsistency in the management regulations of clam fisheries, both vertically and horizontally.

5. Discussion

Our results revealed the critical status of the stocks of the whole commercially exploited clam species along the Catalan coast; where all fisheries have collapsed or are close to collapse. This trend mirrors the evolution of bivalve fisheries in the western Mediterranean Sea, where landings began to plummet in 1997 (FAO-GFCM, 2016). The identification of the causes of the current state of clam fisheries is a complex task, since multiple factors can be involved in the population dynamics of these bivalve species; both natural (*e.g.* environmental parameters such as severe fluctuations of salinity and oxygen, diseases, natural population dynamics, natural predation) and anthropic (*e.g.* fisheries, pollutants, climate change) (Dame, 1996; Orensanz et al., 2006). It is therefore a very difficult and unrealistic exercise to establish a simple cause-effect relationship between only one of these factors and the drop in landings. However, our results, obtained according to the design principles proposed by Ostrom (1990), presented evidence for many management, enforcement failures and factors affecting the sustainability of clam fisheries over time. These gaps were detected in the management of all clam species in all fishing areas, suggesting that the lack of adequate and consistent management and enforcement has strongly contributed to the present situation.

Small scale fishermen are able to manage their resources under certain conditions (*e.g.* Ostrom, 1990). Regrettably, as a direct

consequence of their relatively low economic impact and volume of catches, they have been researched far less than large-scale fisheries and have rarely been regularly monitored by local, national and supranational administrations in the European Union (Weissenberger, 2012; Guyader et al., 2013). They do however constitute a substantial component of the fleet (> 80%) and 40% of employment in the fishing sector (Weissenberger, 2012), providing direct employment for approximately 100,000 people (Guyader, 2007). As well as being important in terms of employment, in some cases they are also locally important in economic terms. They reinforce the attachment people feel for their territory, enhancing social stability in rural and peripheral areas (Guyader et al., 2013). The European Union has been promoting management plans for each type of SSF in the Mediterranean Sea since the "*COUNCIL REGULATION (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea*" (a compulsory regulation for all the European Union member states). However, these management plans, such as the Clam Dredge Fishing Management Plan of 2015, deposit all their weight on principles of "*appropriation and provision regulations and local conditions*", "*monitoring resource and users*" and "*graduated sanctions*"; avoiding such important issues as "*clearly defined user and resource boundaries*", "*collective-choice arrangements*" and "*conflict resolution mechanisms*", etc. which are essential for successful management. An extra effort should be made by the authorities when fisheries target species that play a keystone role in the ecosystem, since a decline in the population of these species may lead to unpredictable changes and cascading effects on the entire ecosystems and as a result an important impact on the economy.

Our study showed different management systems according to the target clam species and the fishing area. Most of these had some degree of co-management between end users (fishermen) and the government (GFD) in the period between 1980 and 2014. Unfortunately, they have not enabled sustainability of these fisheries over time. All of this shows a lack of congruence between appropriation and provision regulations. For example, an experiment performed in 2004 by Baeta and Ramón (2007) compared the catches of the three different mesh sizes (12 × 12 mm; 24 × 24 mm and 29 × 29 mm) used to gather smooth clam in North Barcelona and the results showed that massive numbers of these clams were under the minimum legal size (60 mm) (Fig. 4). Another experiment conducted by Baeta (2006) on wedge clam and venus clam in South Barcelona showed that catches were massively under the minimum legal size (25 mm or 27.2 mm) (Fig. 5). Both experiments proved a complete inconsistency between laws and the resources in reality. In addition, we detected in some fishing areas an absence of any monitoring of resources or enforcement of the regulations by the GFD (with the exception of N and S Barcelona areas with occasional monitoring when a drastic decline on landings was detected); inadequate mechanisms for resolving conflicts between fishermen and other coastal users (in particular those that affect the fishing activity, such as sand extraction for beach renourishment) and sometimes between different types of clam fishermen; and finally deficient nested enterprises (both vertically and horizontally).

We detected that some principles or parts of these principles are strictly respected by all users, whereas others are systematically broken. The first group includes: (1) clearly defined geographical resource limits (between clam fishing areas); (2) user boundaries *i.e.* number of fishing licenses per area and fishing gear; technical boat characteristics (engine power); and (3) few appropriation regulations *e.g.* limitations on working-time (*i.e.* daily work schedule, working days and closed season). The second group includes most of the appropriation regulations: (1) use of legal mesh size; (2) landing limitations (*i.e.* catch weight and minimum legal size) and (3) points of sale. The main difference between both types of regulations is that the first is more easily controlled by the authorities; while the second group is very difficult to control and imply a tremendous inspection effort. Fishermen know this and use this lack of control to avoid such standards and regulations, as has happened with fisheries of all clam species in all fishing areas of the Catalan coast. The questions that automatically arise from this behavior are why do fishermen do this, why do they not respect their regulations, why do they not cooperate with their community? Jentoft (1989) highlighted that only legitimacy could motivate all users to adhere to the regulations. He argued that legitimacy is particularly related with the maximum number of fishermen participating in the regulatory process. Although the regulations and standards were made by local fishermen's guilds and associations of clam fishermen, not all users participated. Only a small group of fishermen (local elites) were responsible for these arrangements, which may contribute to social inequity within the fishing community by creating opportunities and privileges for friends to control resources, which may destabilize social cohesion (Cinner et al., 2012), which can also be harmed by small internal conflicts, rivalries between small groups and personal disputes among fisheries (Jentoft, 2000). Gutiérrez et al. (2011) examined 130 co-managed fisheries around the world, finding among other factors that social cohesion in the fishing community may be a key factor for successful SSF. Fishermen are not homogenous, and their response to a rule also depends on their attitudes, personalities and livelihoods (Gelcich et al., 2005). Clam fishermen are not uniform, because there are subgroups targeting different clam species (wedge clam and striped venus clam) and using different fishing gears in the same fishing area. Each subgroup has different interests. Not even fishermen that target the same species with the same fishing gear are regular, because we observed many rivalries and personal disputes. Therefore, there is no social cohesion in the clam fisheries of Catalonia. Carpenter and Seki (2011) showed a strong correlation between fishermen propensity to cooperate and fishing productivity.

The correlation between fluctuations in catches in different areas of study, which had different management systems and were subject to different levels of fishing pressure strongly suggest that an additional factor to management has affected clam populations along the coast. Mass mortality events affecting many benthic invertebrate phyla (including bivalves) have been detected in recent decades in the NW Mediterranean both at local (from meters to kilometers) and regional scales (> 1000 km of coastline) (Garrabou et al., 2009). Although the direct cause of these outbreaks is still unknown, it has been suggested that global warming may be linked to these episodes (Garrabou et al., 2009; Rivetti et al., 2014). Coma et al. (2009) observed that regional events in the NW Mediterranean coincided with seawater temperature anomalies mainly in summer months. Higher temperatures for prolonged periods of time are the triggering mechanism of prolonged energetic constraints on suspension feeders such as clams, resulting in a longer "summer dormancy" (reduction in their metabolic activity in summer months because of the high temperatures and low availability of food). Under these stress conditions, clams are more vulnerable to diseases involving microbial agents (*e.g. Vibrio* spp.), which act as an opportunistic infection producing mass mortality events (Vezzulli et al., 2010). Massive clam mortalities of commercially important species have been associated with different pathogens (Villalba et al., 1999; Dang et al., 2010). So more research is needed to detect which added factor (pathology, climate change, pollution etc.) has affected commercial clam species on the Catalan coast as well as commercial bivalves in other areas of the Mediterranean Sea.

Our results showed that commercial clam species on the Catalan coast were subjected to intense fishing pressure for decades, suggesting that their populations were in a highly precarious situation. Faced by such vulnerability, any additional stress factor may have trigged the fishery collapse. Then the question arises of how properly managed clam fisheries would have faced these unpredictable events? Defeo (2003) suggested that the effect of these mortalities may swamp management measures. Given the current trend towards global warming, more mortality events can be expected during the following decades (Garrabou et al., 2009). But how can we include these unexpected events in marine resource management? Such unannounced events are

not deeply considered under the eight design principles of common pool resources proposed by Ostrom (1990), but they obviously occur in SSF fisheries as well as other CPR. We suggest that the study of "*how to deal with unexpected events*" should be included as an additional sub-principle of the Principle 2. These types of events can be naturally produced or indirectly human induced (*e.g.* climate change). In order to adapt to them, fishermen could deal with natural disasters by insuring harvests as farmers do. The combination of different types of fishing gears may help to address these types of perturbations at one of the target species.

The enforcement of a long-term strategy with a new management plan is essential to reverse the current situation of low landings. This should be defined to deepen and strengthen the co-management on the basis of the 8 design principles proposed by Ostrom (1990). For the definition of this new management plan, it is essential to work on two different levels. (1) Catalan level or probably at upper management level (northwestern Mediterranean), since the species distribution is not ruled by human administrative limits. In this regard, a genetic study recently carried out by Marie et al. (2016) showed that all the wedge clam inhabiting the entire Mediterranean coast of Spain belong to the same population. This level should include state authorities, fishermen (including all fishing gears, and all fishing areas), since they are targeting the same populations, and scientists. (2) At fishing area level, attention should be focused on the governance and management of the local conditions. It should include the regional authorities, but not only those in charge of managing fishing resources. This should also include other representatives of these sectors that may affect clam fisheries *e.g.* tourism sector; but also fishermen (including all fishing gears and all fishing ports) and scientists. Frangoudes et al. (2008) showed that the improvement of collective governance the implementation of a management plan and the control of the clam exploitation (*i.e. Cerastoderma edule* and *Venerupis decussatus*) by users (fishermen) with the support of the local administration reversed a previous situation of overfished stocks in Galicia (northeastern Spain). Many other conservation measures could also help to improve the sustainability of clam fisheries in Catalonia. As an example Silva-Cavalcanti and Costa (2011) suggested that the creation of no-take areas (protected zones) inside each clam fishing area may act as reproductive reserves, guaranteeing the colonization of the contiguous areas.

The present study is the first work in the literature to report the catastrophic status of clam fisheries on the Catalan coast, as an example of what has occurred to commercial bivalves in the western Mediterranean Sea (FAO-GFCM, 2016). Moreover, it is, to our knowledge, the first study to provide an integrated socio-ecological analysis of the clam fisheries of the Mediterranean Sea. Our results showed that the management of clam fisheries has not been the most appropriate in recent decades, which has strongly contributed to the terrible situation of the main commercial clam species in Catalonia. However, our results also suggest that additional undetermined factors (e.g. pathologies, pollution, climate change, etc.) have affected these species.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2018.01.012.

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